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METHOD FOR PREDICTING THE JET-INDUCED AERODYNAMICS FOR V/STOL C--ETC(U)
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METHOD FOR PREDICTING THE JET-INDUCED AERODYNAMICS OF V/STOL CONFIGURATIONS IN TRANSITION

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A method for predicting the propulsive induced aerodynamics of a VSTOL aircraft in the transition flight regime is presented. This method is applicable to low-wing, circular jet subsonic VSTOL configurations with normally exhausting jets. Validation results for various VSTOL configurations are also presented.

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SUMMARY

A method for predicting the propulsion-induced aerodynamics of a VSTOL aircraft in the transition flight regime has been developed. This method represents the formulation of wind tunnel test data consisting of pressure coefficients at numerous locations on a flat plate due to a circular jet exhausting normally into crossflows of freestream to jet velocity ratios from 0.1 to 0.3. As a result, the method is applicable to low-wing, circular jet subsonic V/STOL configurations with normally exhausting jets.

This report documents the development of the formulation along with validation results for various V/STOL configurations indicating its applicability as well as limitations. The computer code used in the validation of the method is also presented along with the required input and configuration modelling procedures.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS

AR	Aspect Ratio
C_p	Pressure coefficient
$C_{p_{MAX}}$	Maximum pressure coefficient for a particular velocity ratio
$C_{p_{NORM}}$	Pressure coefficient normalized by $C_{p_{MAX}}$
D_e	Equivalent diameter - diameter whose circular area equals the total exit area of all jets in the configuration
D_j	Jet diameter
L	Lift; total length of configuration
M	Pitching moment
p	Pressure
q	Dynamic pressure
S	Planform area
S_j	Jet exit area
V_e	Equivalent velocity ratio - $\frac{V_\infty}{V_j}$
V_j	Jet Velocity
X	Longitudinal distance along aircraft centerline
Y	Lateral distance from aircraft centerline

Subscript

∞	Freestream

Mathematical Symbol

$\Delta(\ )$	Incremental quantity

INTRODUCTION

The V/STOL transition flight regime covers the velocity range from low speed hover to the sustained velocity required for fully wingborne flight. Jet exhaust effects have a major influence on aerodynamic characteristics in this regime resulting in large forces and moments being induced on the aircraft. These jet effects involve the interaction of the jet and free stream flow and are primarily the result of four viscous flow phenomena: jet blockage, wake separation, entrainment, and vortex generation. Due to complex viscous interaction of these four phenomena, the individual effect of each component has not been separated, making analytical/numerical prediction most difficult.

Current prediction techniques applicable to the transition flight regime consist of potential flow analysis computer programs with empirically derived adjustments or corrections to account for the viscous interactions which characterize transition aerodynamics. These techniques are extremely time consuming with respect to modelling the aircraft configuration with panels required by the potential flow analysis, and also with respect to the computer time required to run the program. Unfortunately, this time expended does not necessarily result in an associated increase in accuracy. As a result, these techniques are primarly applicable to detailed design type of analysis, being too expensive for use as a preliminary design tool.

The methodology presented here represents the development of a prediction technique which is designed for use as a preliminary design tool. The induced lift and pitching moment are calculated requiring only the configuration geometry and jet location. Since most of the available experimental data applicable to the transition flight regime resulted from specific aircraft configurations, it was decided to use the more fundamental data obtained from tests of jets issuing from flat plates. This data formed the basis of the prediction technique which could then be applied or adapted to most aircraft configurations.

Prior to the formal publication of this report, this method was used as the basis for a more complete prediction technique for V/STOL transition aerodynamics with no restrictions concerning aircraft configuration. Coefficients are applied to the basic lift loss value calculated by the method contained herein to account for various configuration effects including wing aspect ratio, longitudinal position of the jet, wing height, lateral spacing of multiple jets, nozzle configuration, and jet deflection angle. A complete discussion of the development of the more complete technique is contained in reference (6).

METHOD DEVELOPMENT

The preliminary design stage of a V/STOL aircraft involves the assessment of various conceptual designs to determine which concept most satisfies the design requirements to justify further development. As part of this assessment, the propulsion induced aerodynamic effects must be predicted to ensure the selection of that design which, when weighed against the other design requirements, minimizes the negative effects and maximizes the positive effects.

In developing a method to predict the propulsion induced effects in such a design environment, the design information required by the method must be limited to that which would be known at that stage. Accordingly, the present method was developed under the guidelines of requiring only general configuration geometry, jet location, and free stream-to-jet velocity ratio for the desired flight conditions. The approach then taken to develop this generalized, preliminary design stage type of empirical formulation to predict the transition aerodynamics was to:

a. Obtain available pressure coefficient data measured on a large flat plate due to a jet exhausting perpendicular to the free stream.

b. Derive an expression for the pressure coefficient data as a function of velocity ratio, V_e, and longitudinal and lateral distances from the jet, X/D and Y/D respectively.

c. Use the finalized expression as a basis to integrate over the configuration planform area of interest relative to nozzle location to obtain the jet induced aerodynamics in transition flight.

d. Validate the resulting method initially using simplified flat plate or low wing configurations followed by more realistic complex designs.

e. Modify or adjust the expression, based on results of step (d) to account for configuration variables such as jet nozzle location relative to wing and fuselage, planform-to-jet area ratio, jet deflection, and fuselage contour.

The pressure coefficient data used to develop the empirical formulation was obtained from flat plate data generated by Fearn, reference (1). This data was obtained for free stream-to-jet velocity ratios ranging from 0.1 to 0.45 using a four-inch diameter jet exhausting normally from a flat plate 24 jet diameters wide by 27 diameters long. The pressure coefficient was defined as

$$C_p = \frac{p - p_\infty}{q_\infty}$$

where p is the difference between the pressure measured at the test condition and the pressure measured with the power off, and p_∞ is the static pressure of the free stream fluid. Thus, the data represents the induced effects produced by the jet. As plotted in figures (1) to (4) the data approximates an exponential trend with X/D which tends to flatten out as Y/D is increased, with a non-linear peak value variation with V_e. In developing an expression to fit this data, each of these variations must be accounted for plus the variation of the X/D location of the peak values for a particular V_e, as emphasized in Figure (4).

The equations representing the induced pressure coefficient data were developed in essentially two parts. The first part, $C_{P_{MAX}}$, equation (1), calculates the peak pressure coefficient as a function of Y/D_e and V_e. The second part, $C_{P_{NORM}}$, equation (2), represents the remaining normalized data points (normalized by the peak Cp value, $C_{P_{MAX}}$, for each V_e). The two equations are then simply multiplied according to equation (3) to obtain the desired induced pressure coefficient.

$$C_{P_{MAX}} = \frac{-4.25}{e^{\frac{(4V_e - 1)^2}{(Y/D_e + .5)^{(3.25\ V_e + 1.4)}}}} \tag{1}$$

$$C_{P_{NORM}} = \frac{1}{e^{[K_1\ (X/D_e - F)]^{K_2}}} - \frac{(3.67\ Y/D_e + 5)\ V_e^4}{e^{(X/D_e + .4\ Y/D_e + 2.5)^2}} \tag{2}$$

$$F = (2.48\ Y/D_e - 1.6)V_e - .1\ Y/D_e - .07$$

and for $(X/D_e - F) \leq 0$

$$K_1 = \frac{1}{(-2.28\ V_e + 1.36)\ Y/D_e}$$

$$K_2 = \frac{16\ V_e}{Y/De} + 1.55\ \ln\ (Y/D_e) - 1$$

whereas for $(X/D_e - F) \geq 0$

$$K_1 = \frac{1}{1.1\ Y/D_e}$$

$$K_2 = -.13(Y/D_e - 3.5)^2 + 1.8$$

$$C_P = C_{P_{MAX}}\ C_{P_{NORM}} \tag{3}$$

In equation (1), the constant -4.25 establishes the maximum value which $C_{P_{MAX}}$ attains. The term $e^{(4V_e-1)^2}$ accounts for the exponential variation of $C_{P_{MAX}}$ values as shown in Figure (2), with the term

$$(Y/D_e + .5)^{(3.25\ V_e + 1.4)}$$

providing the variation in $C_{P_{MAX}}$ values with Y/D_e and V_e which tends to flatten the C_P curves as Y/D_e increases, as seen in Figures (1) to (4).

The first part of the $C_{P_{NORM}}$ equation

$$\frac{1}{e^{[K_1\ (X/D_e - F)]^{K_2}}}$$

establishes the basic exponential shape of the curve, being a version of the general equation $\frac{1}{e^{(ax)^b}}$. Replacing the x term by $(X/D_e - F)$ accounts for the X/D_e shift in the $C_{P_{MAX}}$ values with varying V_e and Y/D_e as indicated in Figures (1) to (4). The term K_1 represents the coefficient of x required to curve fit the data and provides a corrective effect to insure the exponent remains positive. The overall exponential shape of the curve is made symmetrical about the ordinate axis by the factor K_2 which again varies with V_e and Y/D_e. The second term of the $C_{P_{NORM}}$ equation

$$\frac{(3.67\ Y/D_e + 5)\ V_e^4}{e^{(X/D_e + .4\ Y/D_e + 2.5)^2}}$$

modifies the original shape of the curve at high negative X/D_e values to account for the positive pressure coefficient in front of the jet.

With the equation developed in this form, the calculation of induced pressure coefficients is relatively simple. However, calculating the induced forces for an entire configuration is more amenable to use of the computer. As a result, the formulation was computerized with a configuration modelling technique and an integration procedure included as part of the code. The modelling technique and integration procedure are discussed in Appendix A. A listing of the computer program, a discussion of the required input, and a sample output are then presented in Appendix B.

METHOD VALIDATION

Since the data used for formulation represents pressures on a flat plate due to normally exhausting jets, the method mainly applies to low wing configurations with a normally exhausting jet. The jet should be centrally located in the fuselage or wing undersurface, away from wing or fuselage edges which would result in additional circulation effects not contained in the data. Additionally, nozzle pressure ratios during the test indicate the method to be applicable to subsonic configurations. Therefore, the method was validated against configurations commensurate with its capability plus additional configurations to indicate possibilities for extending its capability.

The first correlation of the method was done with data from reference (2) for a rectangular wing. Figure (5) shows fairly good agreement for both lift and resulting pitching moment, especially since the data contains some circulation effects causing the apparent over-prediction of induced lift loss while the method does not contain circulation effects.

Figure (6a) shows the correlation of data, also from reference (2), for an elongated body with a jet located 40% from the leading edge. Excellent results are shown for jet induced lift while the pitching moment exhibits fair correlation. Additional comparisons with the same elongated body but with the jet located 60% from the leading edge are shown in Figure (6b). Very good agreement again is shown between the test data and predicted results.

For a delta wing configuration with a small jet, also from reference (2), excellent agreement with test data is shown in Figure (7a) for a velocity ratio range of 0.1 to 0.3. This velocity range is representative of the lower and middle transition region and thus a good correlation in this range is considered to be of primary importance. The corresponding pitching moment plot, however, indicates gross disagreement. This is due to questionable data since the aberrant points on the plot represent a large hump in the data which substantially deviates from the trend.

Results of replacing the small jet with a larger jet in the same delta wing configuration are shown in Figure (7b). For this configuration, the predicted results for jet induced lift are slightly greater than actual test data, but again this difference is small. Excellent agreement for pitching moments is shown between the predicted results and test data for the velocity range 0.1 to 0.3.

Further validation was conducted with a delta wing design from reference (3). Figure (8a) shows the comparison to be fair for the configuration with a jet to planform area ratio of 0.006, whereas increasing the ratio to 0.024 produced quite good results as indicated in Figure (8b).

To determine the possibilities of extending the method application to multiple jet configurations, data from reference (4) for a four jet arrangement of the same configuration as above was used for comparison. The method was applied in the same manner as before for each jet, however a thrust weighted summation was used to obtain the total induced force as given by

$$\frac{\Delta L}{T} = \left(\frac{\Delta L}{T}\right)_i \frac{T_i}{T_{total}} + \left(\frac{\Delta L}{T}\right)_{i+1} \frac{T_{i+1}}{T_{total}} + \ldots + \left(\frac{\Delta L}{T}\right)_n \frac{T_n}{T_{total}}$$

where $(\Delta L/T)_i$ and T_i are the induced lift and thrust associated with an individual jet, and T_{total} is the total thrust of the configuration. Figure (8c) contains a planform view of the configuration along with results of the comparison, indicating excellent agreement up to velocity ratio of 0.15, where the prediction begins to diverge into only fair agreement at Ve = 0.25.

A final validation of the method was done using data from reference (5) for a high wing configuration. This represents an additional extension of the method's applicability beyond the low wing type of configuration. As shown in Figure (9), the comparison is quite good for the single jet configuration indicating wing height to be a secondary effect in this design. However, Figures (10a) and (10b) indicate an important limitation of this method being the inability to account for additional circulation created by a jet located near the trailing edge of a wing. The additional lift and subsequent reduction in induced lift loss associated with such a jet/wing arrangement is clearly illustrated in the figure.

CONCLUSIONS AND RECOMMENDATIONS

The method developed herein to predict the propulsion induced lift of a V/STOL aircraft in the transition flight regime has been shown to be quite effective. When applied to those configurations which do not exceed the limitations imposed by its development, the method's predictions are well within the accuracy required of a preliminary design phase analysis technique.

However, these limitations require that further development of the method be directed towards extending its capability to include other configuration variables. These variables include nozzle location relative to the wing, jet deflection angle, and sideslip conditions. Additionally, nozzle pressure ratio effects must also be included to allow prediction of supersonic V/STOL configurations which are typically characterized by one or more high nozzle pressure ratio exhaust jets.

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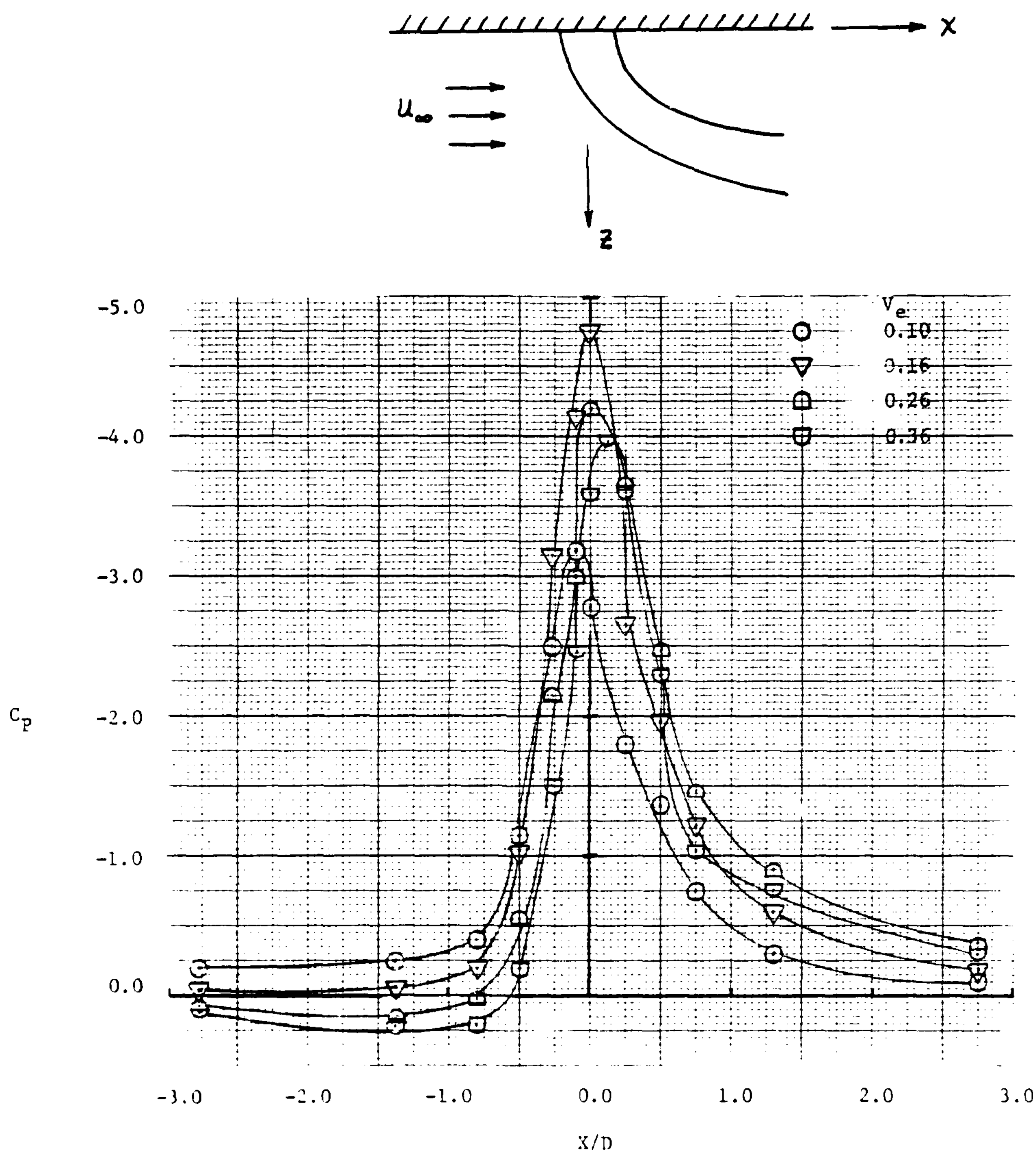


FIGURE 1. Pressure Coefficient Distribution for V_e = .1 ~ .36, Y/D = 0.5

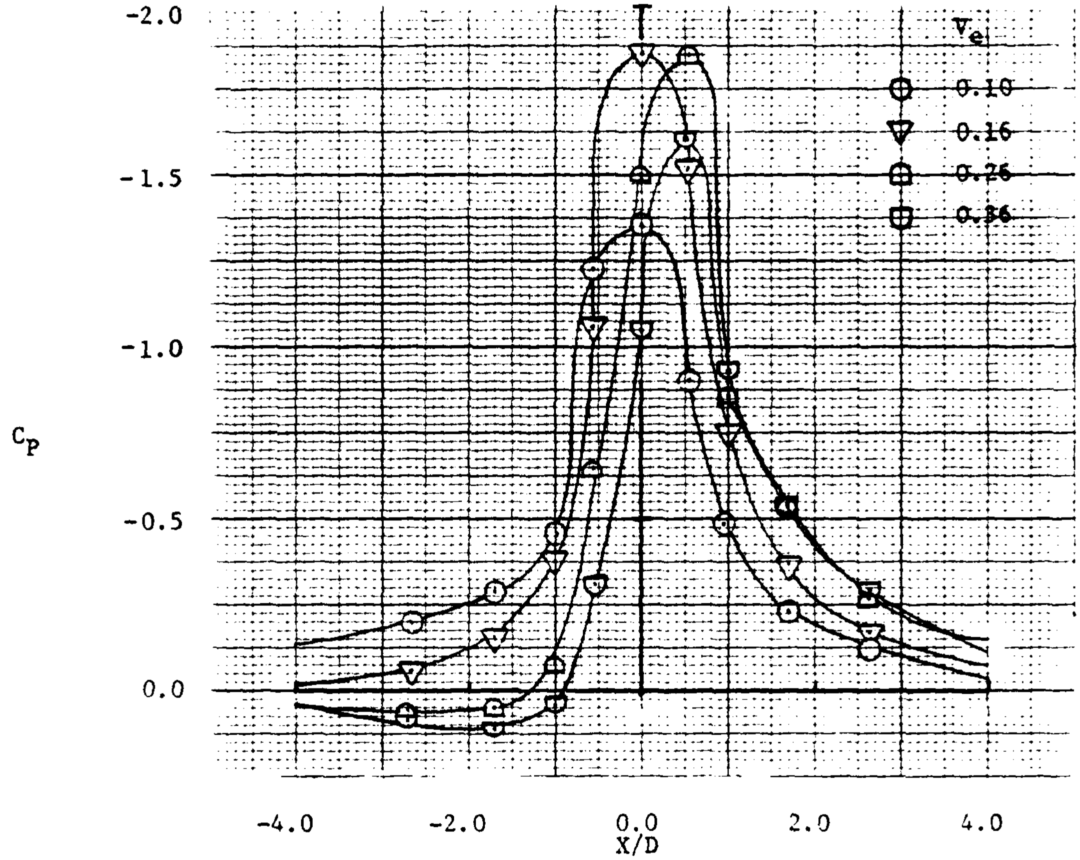


FIGURE 2. Pressure Coefficient Distribution for V_e = .1 - .36, Y/D = 1.0

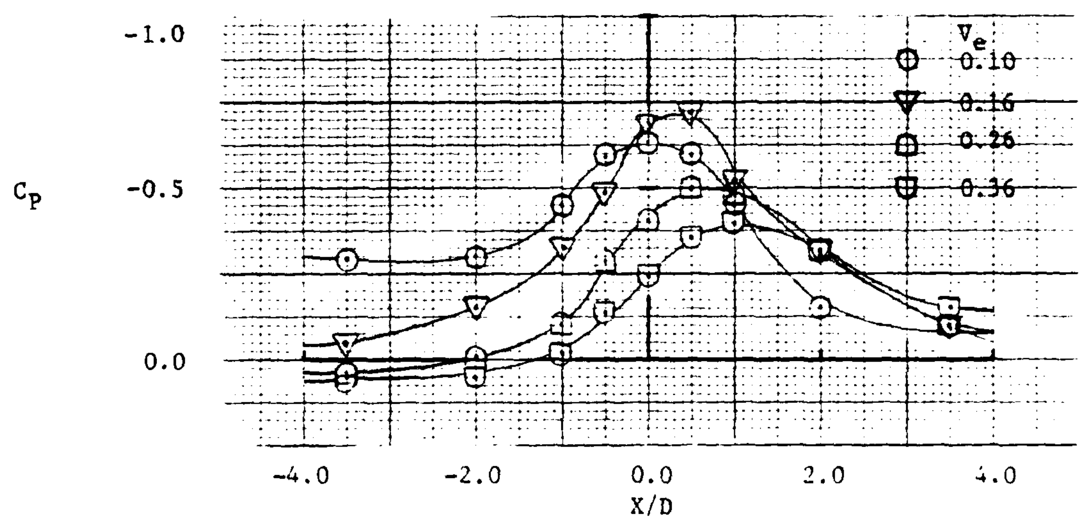
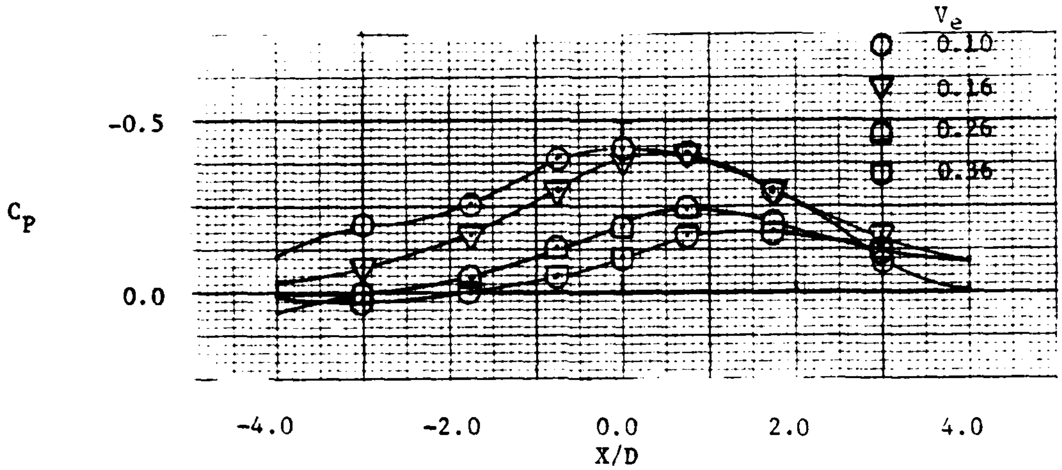
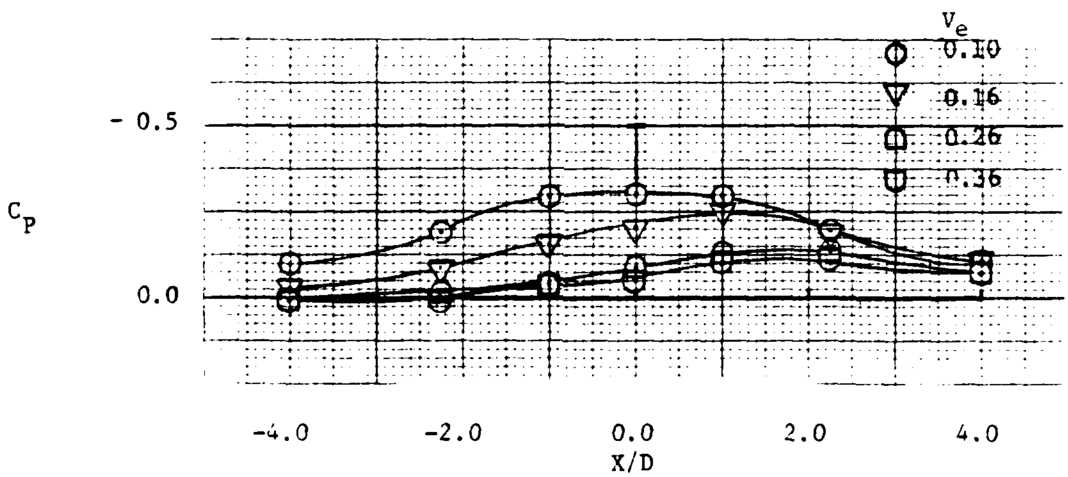


FIGURE 3. Pressure Coefficient Distribution for V_e = .1 - .36, Y/D = 2.0



a. Y/D = 3.0



b. Y/D = 4.0

FIGURE 4. Pressure Coefficient Distribution for V_e = .1 - .36, (a) Y/D = 3.0, (b) Y/D = 4.0

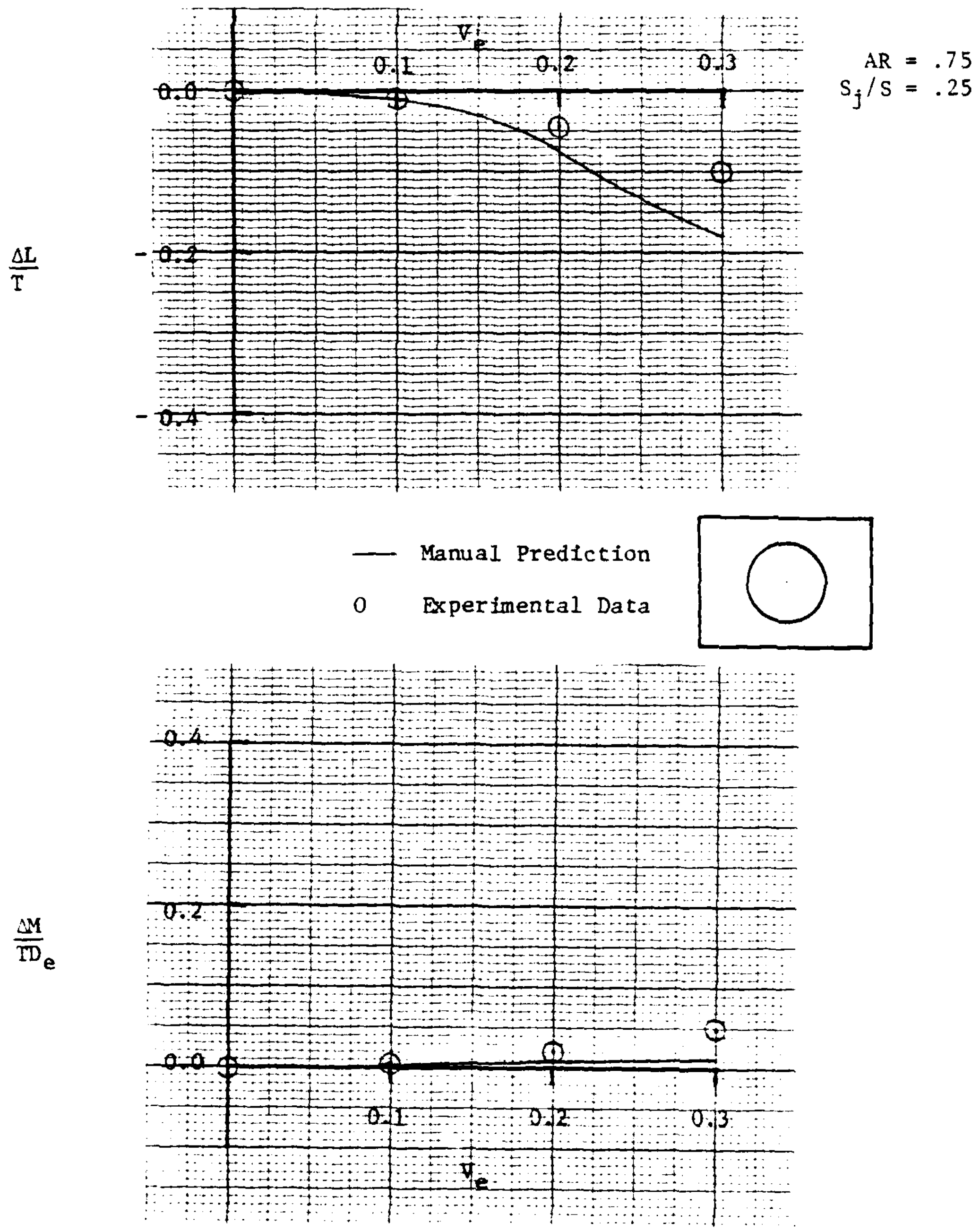
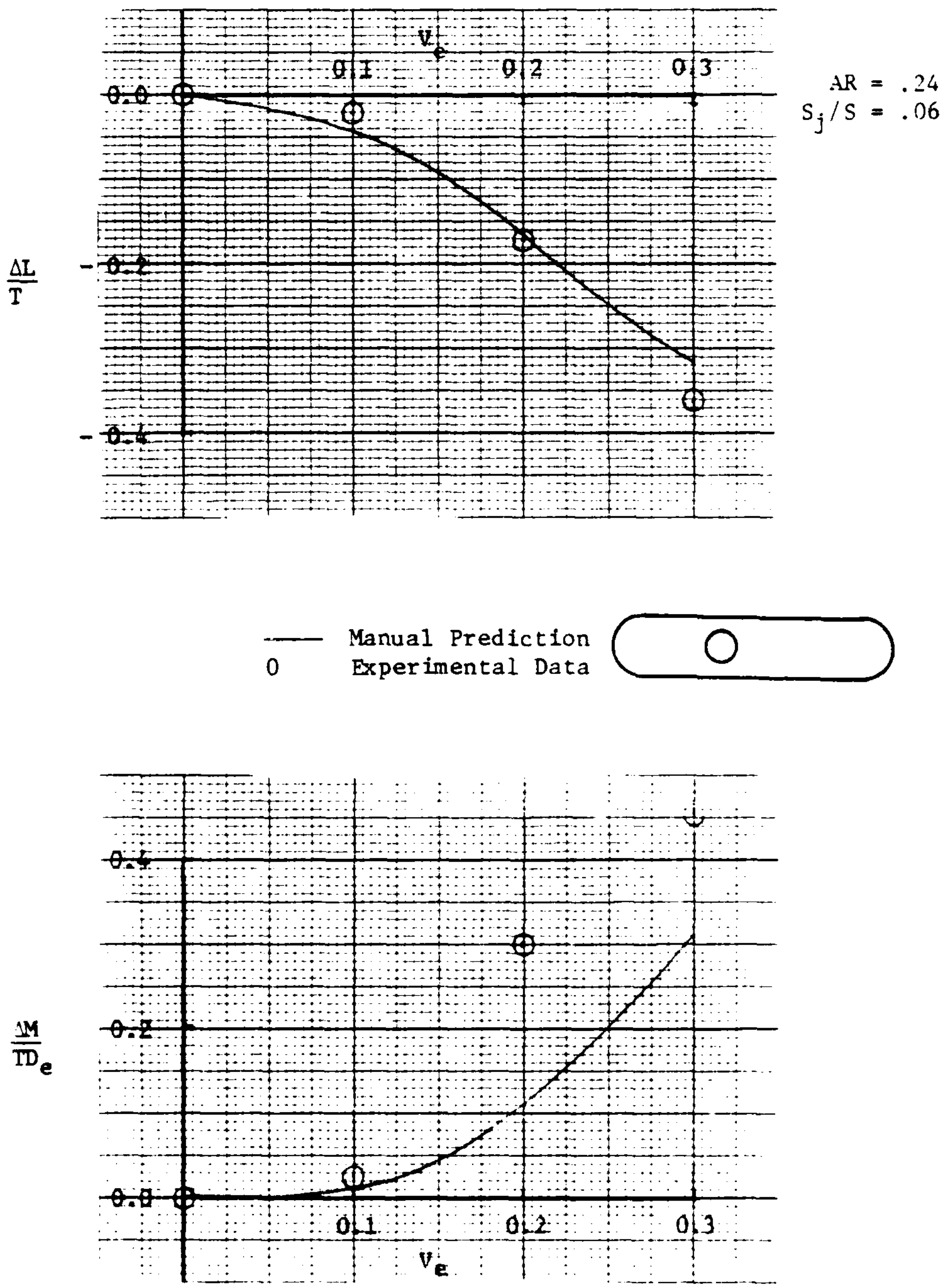
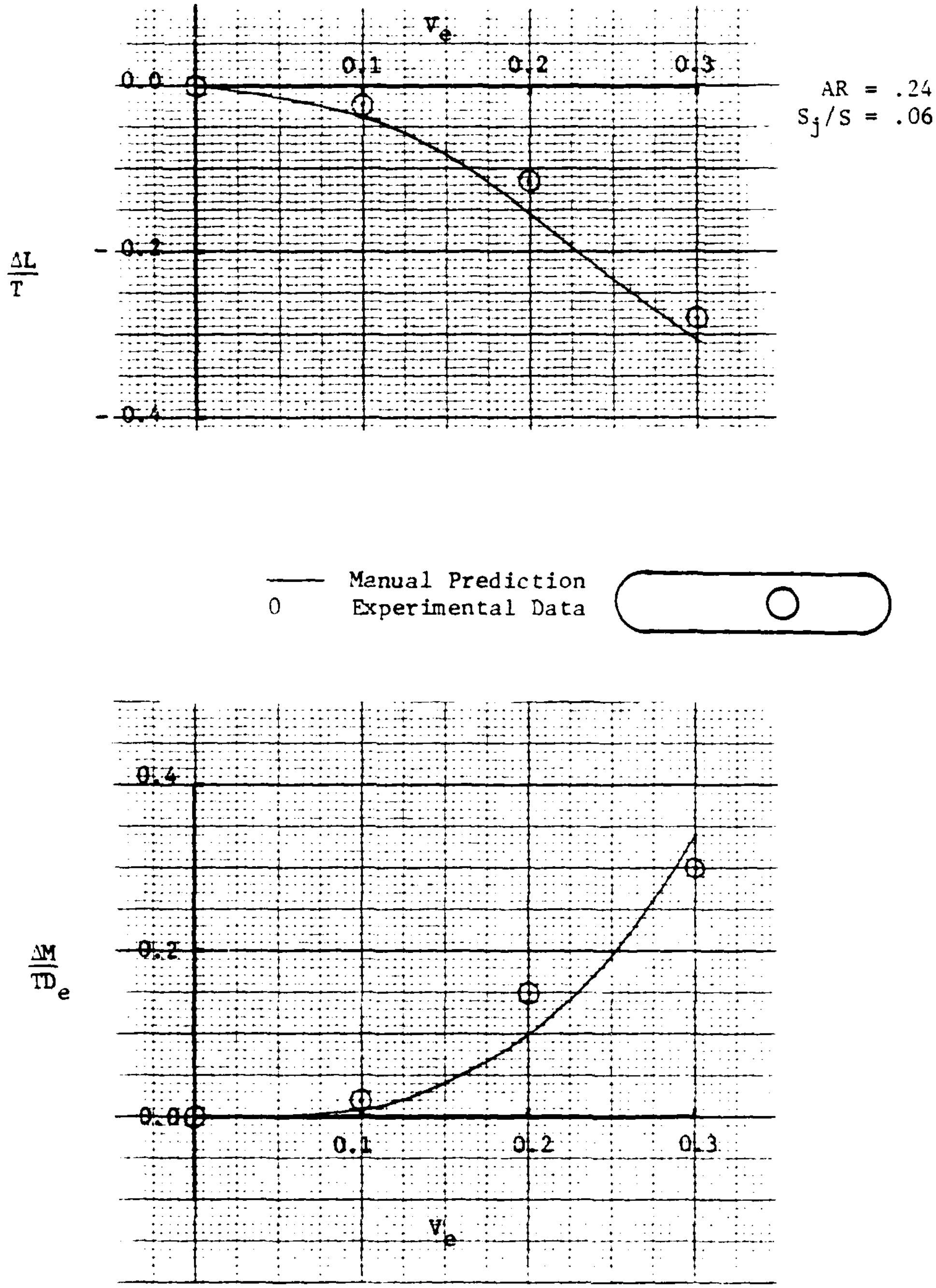


FIGURE 5. Comparison of Predicted Results with Test Data of a Rectangular Wing



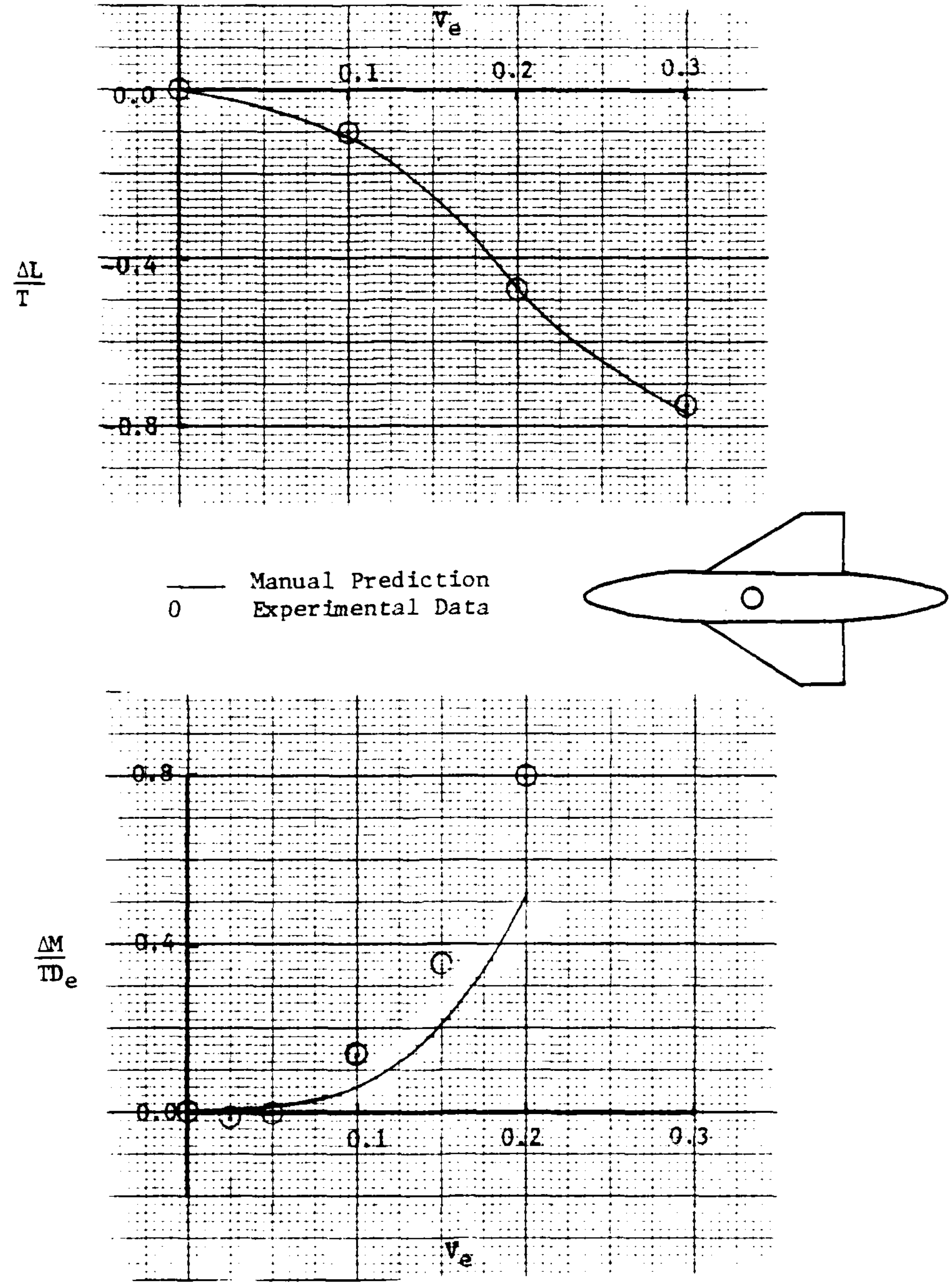
a. $X/L = 0.40$

FIGURE 6. Comparison of Predicted Results with Test Data of an Elongated Body



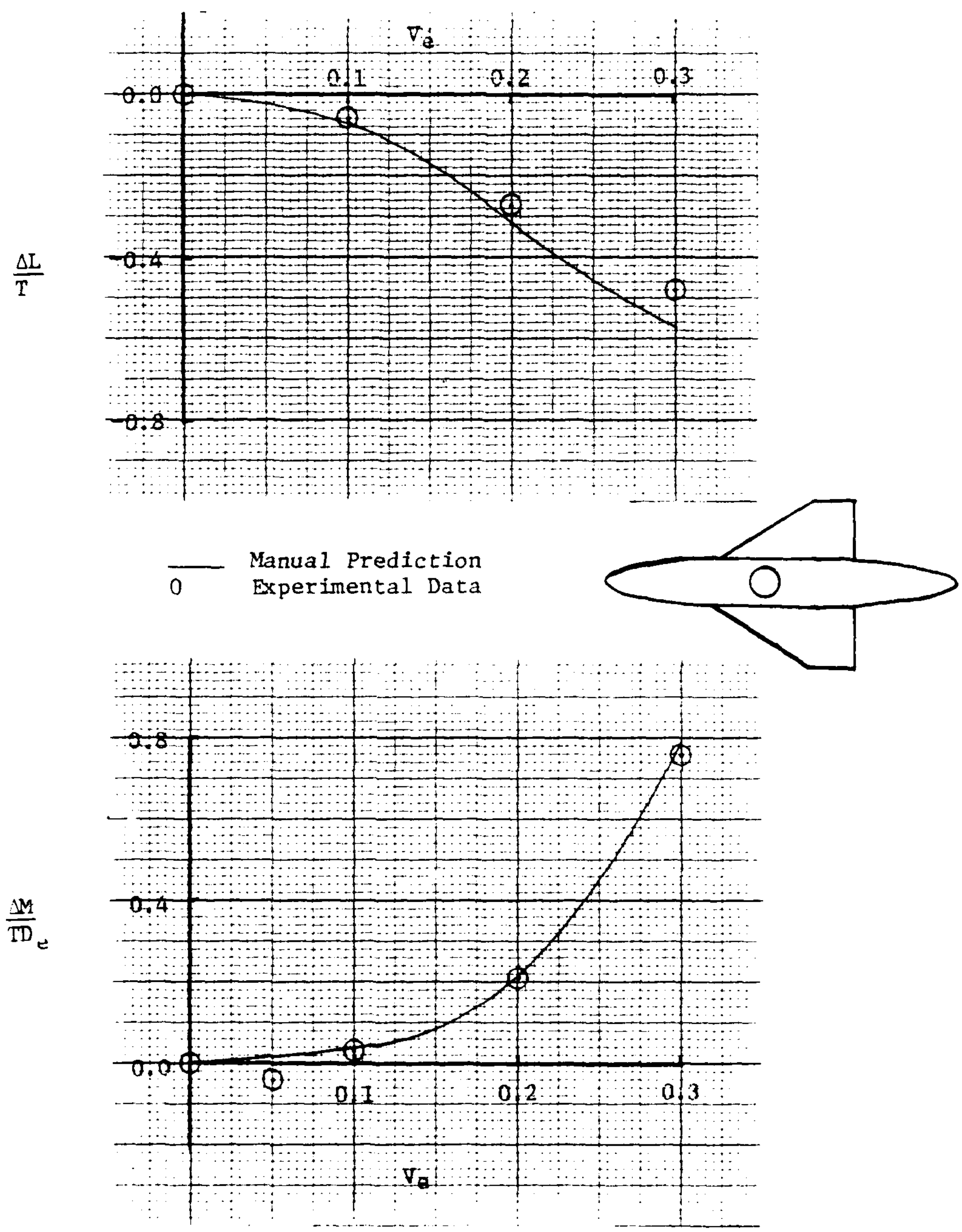
b. X/L = 0.60

FIGURE 6. Continued



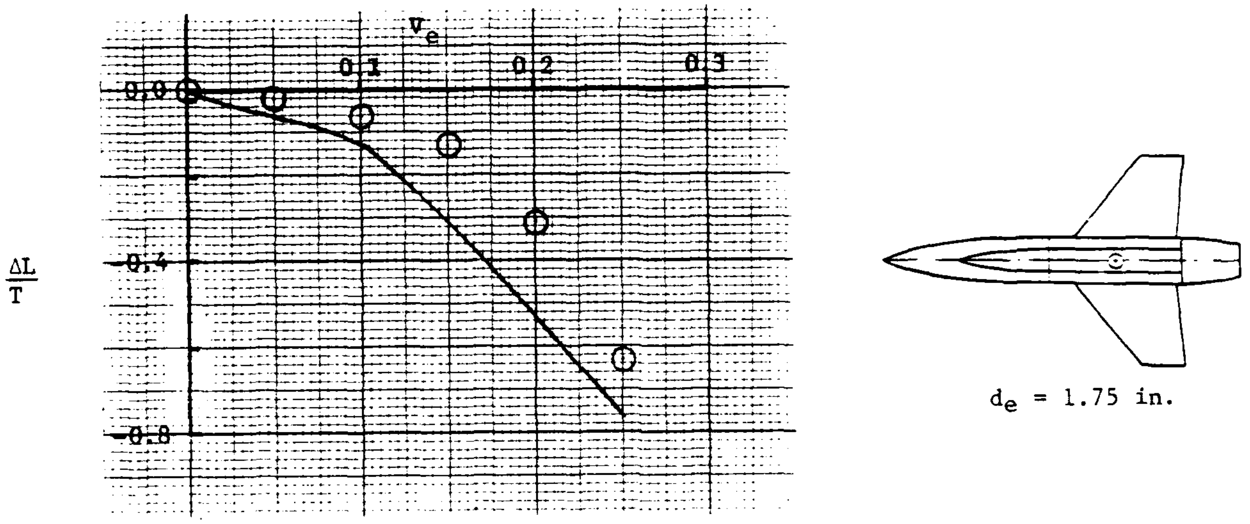
a. $S_j/S = 0.013$

FIGURE 7. Comparison of Predicted and Experimental Data of a Clipped Delta Wing Configuration



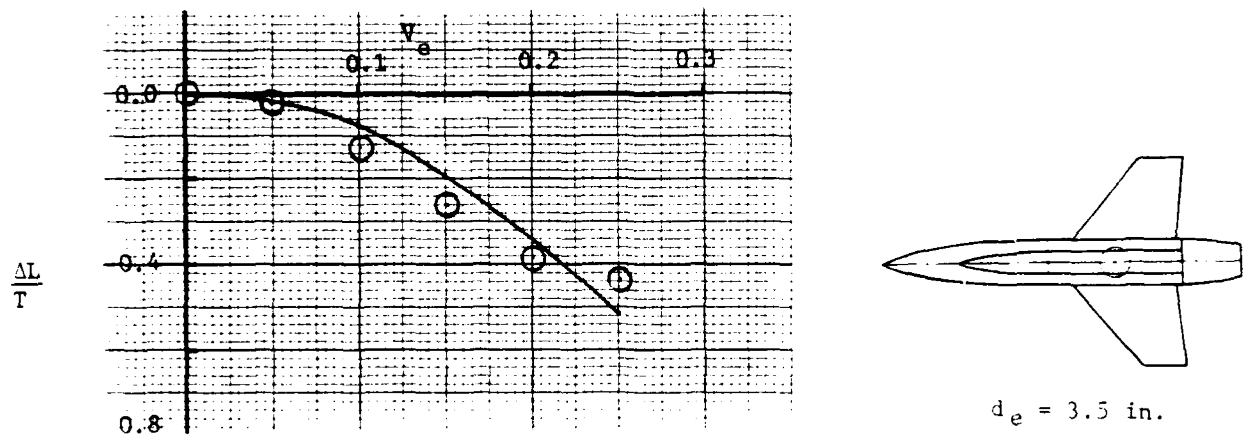
b. $S_j/S = 0.026$

FIGURE 7. Continued



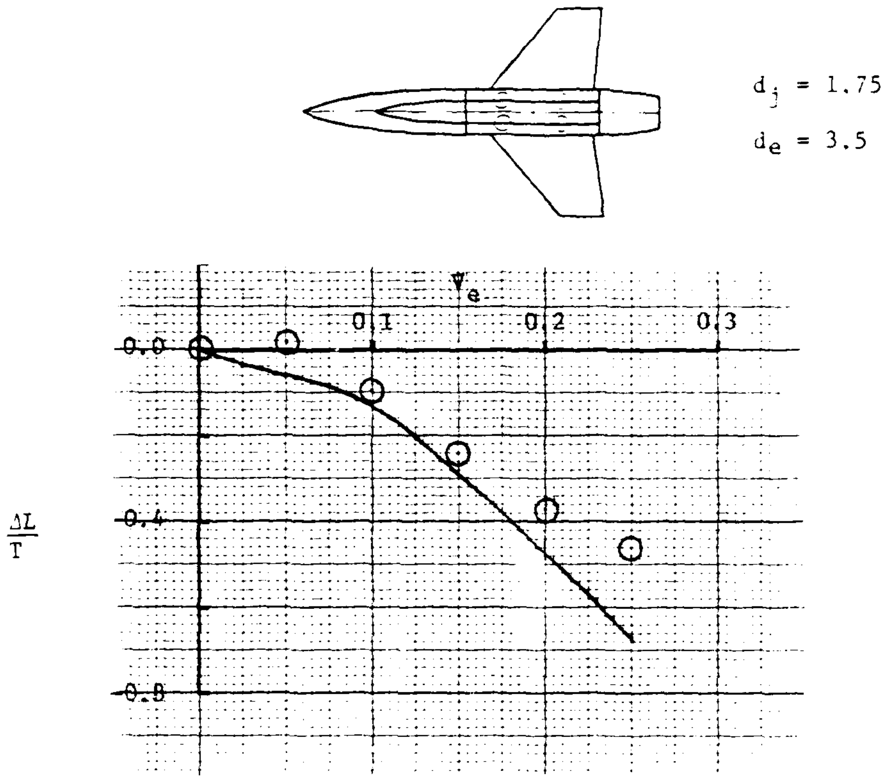
a. Single Jet Configuration, $S_j/S = 0.006$

——— Manual Prediction
0 Experimental Data



b. Single Jet Configuration, $S_j/S = 0.024$

FIGURE 8. Comparison of Predicted and Experimental Data of Clipped Delta Wing Configuration



c. Four Jet Configuration, S_j/S = 0.024

FIGURE 8. (Continued)

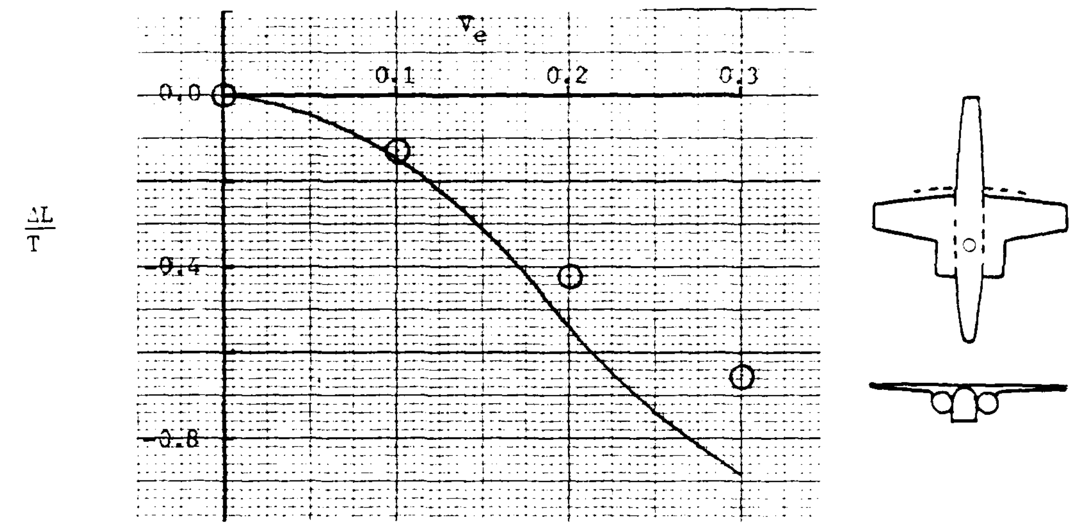
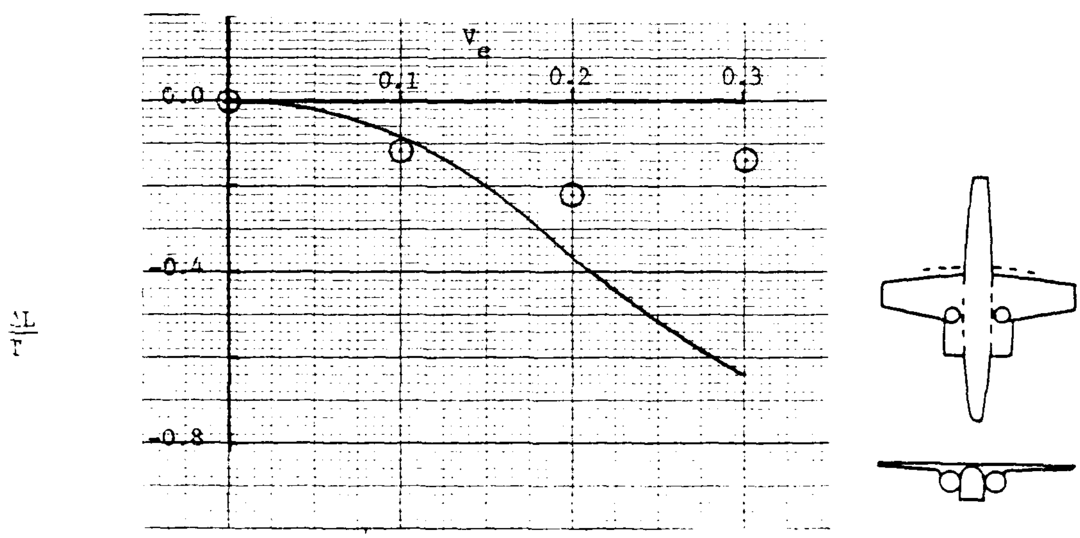
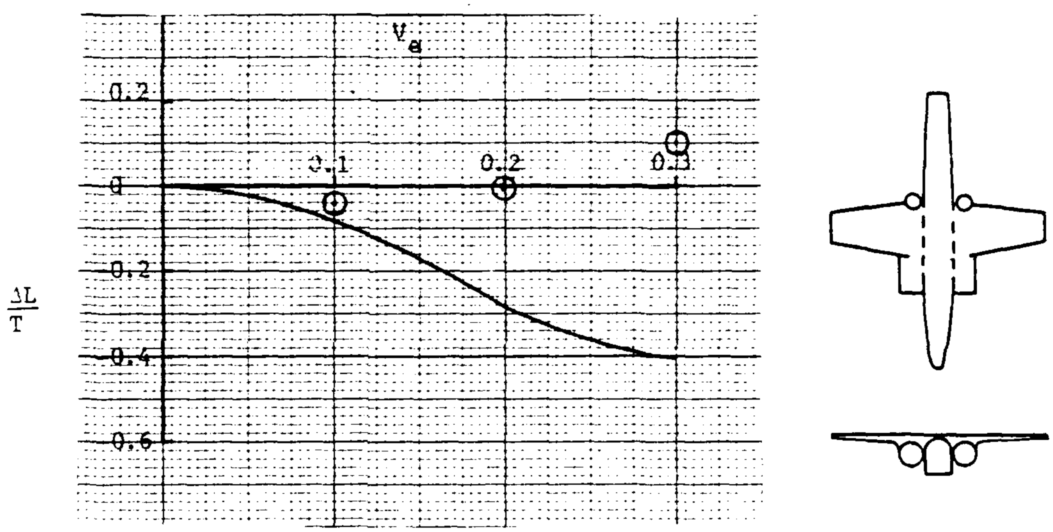


FIGURE 9. Comparison of Predicted and Experimental Data of a Single Jet High Wing Configuration



a. Nozzles Forward

FIGURE 10. Comparison of Predicted and Experimental Data of a Two-Jet, High Wing Configuration



b. Nozzles Aft

FIGURE 10. Continued

APPENDIX A

MODELLING AND CALCULATIONS PROCEDURES

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Modelling the Configuration

A simple panelling method using rectangular segments to approximate the geometry of the planform is used to input the desired configuration. As shown in Figure (A-1), the length of these rectangular segments is restricted only by the size of the configuration, with the width being dictated by the accuracy with which the curved and angled aircraft components are to be modelled. To further refine the calculation of the induced pressures within each rectangular segment, an integration interval is used and required as input by the computer program which defines the longitudinal and lateral grid of rectangular elements. The mid-point of these elements defines the point at which actual pressure coefficient calculations are made.

The only caution to be heeded when panelling the configuration is that sufficiently small elements are defined in the area around the jet to enable accurate calculation of the rapidly changing induced pressures associated with this area. Conversely, modelling of the planform at distances beyond five jet diameters from the jet is not critical since induced pressures are negligible beyond this distance.

Once the configuration is panelled, the computer program is structured to calculate the induced pressures for any number of different velocity ratios. This can be done by simply inputting the number of cases to be run and the associated values of velocity ratio; a more detailed discussion of which is given in the computer program section.

Integration Procedure

The integration procedure used to exercise and validate the developed method consists of the incremental form of the equation

$$\frac{\Delta L}{T} = \frac{2}{\pi} \frac{q_\infty}{q_j} \iint C_p \, d(X/D) d(Y/D)$$

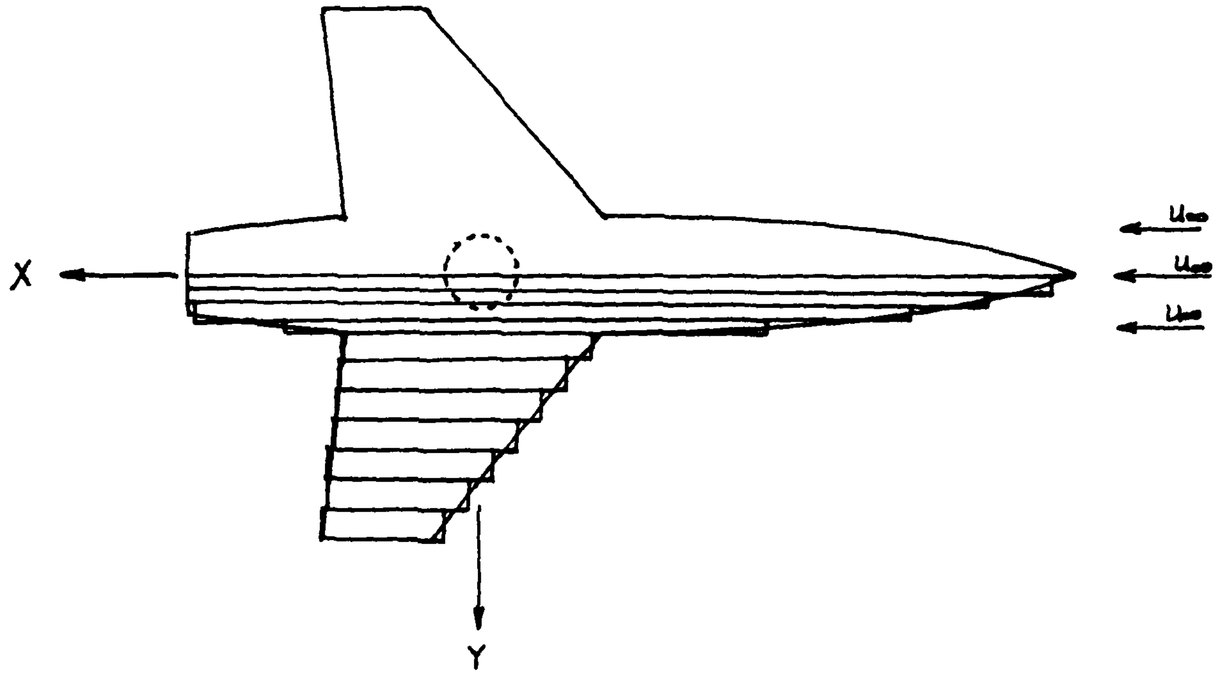
The procedure used involves the following steps:

(1) Pressure coefficients calculated at various longitudinal stations for a constant span station are plotted, with the area under the curve calculated assuming the pressure coefficient to be constant across the various longitudinal intervals.

(2) Step 1 is repeated for each span station at which pressure coefficients are calculated.

(3) The resulting forces per station are then plotted against their particular span station to again calculate the area under the curve which results in the total induced force. This procedure is followed for each rectangular segment. The resultant pressure coefficient and induced lift of each segment is then summed for all segments to obtain the induced lift for the total planform.

The accuracy of this procedure is dependent upon the integration interval chosen. This is especially true in close proximity to the jet exit when the surface pressure variations are quite large for only small changes in location.



NOTES:

1. Rectangular segments are smaller near the location of the jet than those farther away. Some consideration must be given in determining the integration intervals.

2. Rectangular segment lengths are sized for accuracy in modelling the planform contour.

3. For applicable configurations, only half of configuration panelled, with results multiplied by two for symmetry.

4. Jet center is considered to be the origin with the central most panel(s) offset from the origin to avoid a zero value for Y/D.

5. All lengths are non-dimensionalized by the jet diameter. Accordingly, all input data for any configuration should be similarly non-dimensionalized.

FIGURE A-1. Schematic of Configuration Panelling Procedure

APPENDIX B

COMPUTER PROGRAM

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Computer Program

An interactive computer program was developed to facilitate the calculation of the jet induced pressure coefficient over any configuration planform. The program contains equations (1) to (4) with which to calculate the pressure cofficients for any given point, the methodology with which to panel the configuration planform, and the integration routine to calculate the induced lift from the pressure distribution. Programing these equations has also enabled calculation of the pitching moment resulting from the planform pressure distribution according to equation (A-1)

$$\frac{\Delta M}{TD_j} = \sum_{i=1}^{n} \left(\frac{\Delta L}{T}\right)_i \frac{X_i}{D_j} \qquad \text{(A-1)}$$

where

$\left(\frac{\Delta L}{T}\right)_i$ = induced lift of a particular panel

$\frac{X_i}{D_j}$ = the X location of the panel center of pressure

n = number of panels used to simulate the planform

The planform center of pressure is then calculated according to equation (A-2)

$$\frac{\bar{X}}{D_j} = \frac{\frac{\Delta M}{TD_j}}{\frac{\Delta L}{T}} \qquad \text{(A-2)}$$

As output, the program provides the pressure coefficient, induced lift, pitching moment, and center of pressure for each panel used to model the planform and for the entire planform. A listing of the program along with a sample input and resulting output is contained at the end of this appendix.

Computer Program Input

The input required by the computer program consists of data required to panel the configuration planform, the jet location, and the equivalent velocity ratio. This input is tabulated below.

COMPUTER INPUT

ITTL	Case Title (Up to 80 Characters)
NCOMP	Number of rectangular segments
NVE	Number of velocity ratios
VE	Velocity ratio
DELXY	Integration interval into which rectangular segments are divided (interval for both x and y directions; different values can be input for the various segments)
XOD1	Minimum x-coordinate of rectangular segment
XOD2	Maximum x-coordinate of rectangular segment
YOD1	Minimum Y-coordinate of rectangular segment
YOD2	Maximum Y-coordinate of rectangular segment

XOD1, XOD2, YOD1, YOD2 must be repeated for each rectangular segment.

SAMPLE INPUT

```
-MONA
 INPUT TITLE
? ELONGATED BODY  X/C=.40
 INPUT NUMBER OF COMPONENTS
? 2
 INPUT NUMBER OF VELOCITY RATIOS AND VALUES
? 6,.05,.10,.15,.20,.25,.30
 INTEGRATION INTERVALS EQUAL? YES=1,NO=0
? 1
 INPUT INTEGRATION INTERVAL
? .1
 INPUT X1,X2,Y1,Y2 FOR EACH PANEL
? -2.90,4.40,.10,.70
? -2.65,4.15,.70,.90
   COMP      X1          X2          Y1          Y2
     1     -2.9000     4.4000      .1000       .7000
     2     -2.6500     4.1500      .7000       .9000
 IS INPUT CORRECT?  YES=1,NO=0
? 1
     STOP
       .304 CP SECONDS EXECUTION TIME
```

SAMPLE OUTPUT

```
ELONGATED BODY  X/C=.40

    COMP      X1          X2          Y1          Y2
      1     -2.9000     4.4000      .1000       .7000
      2     -2.6500     4.1500      .7000       .9000

 COMP  1
 -------

 X1= -2.90     X2=  4.40
 Y1=   .10     Y2=   .70
 DELXY= .10      NY=  7

 RESULTS MAY BE INVALID FOR VE LESS THAN 0.1
      VE=      .0500     CPT=    -2.2571     DLOT=     -.0036
      VE=      .1000     CPT=    -1.6984     DLOT=     -.0108
      VE=      .1500     CPT=    -1.9678     DLOT=     -.0282
      VE=      .2000     CPT=    -2.1781     DLOT=     -.0555
      VE=      .2500     CPT=    -2.2167     DLOT=     -.0882
      VE=      .3000     CPT=    -2.0242     DLOT=     -.1180

 COMP  2
 -------

 X1= -2.65     X2=  4.15
 Y1=   .70     Y2=   .90
 DELXY= .10      NY=  3

 RESULTS MAY BE INVALID FOR VE LESS THAN 0.1
      VE=      .0500     CPT=     -.5436     DLOT=     -.0009
      VE=      .1000     CPT=     -.6827     DLOT=     -.0043
      VE=      .1500     CPT=     -.7296     DLOT=     -.0105
      VE=      .2000     CPT=     -.7453     DLOT=     -.0190
      VE=      .2500     CPT=     -.7029     DLOT=     -.0280
      VE=      .3000     CPT=     -.6036     DLOT=     -.0346


 TOTALS- SUM OF COMPONENTS
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    VE        TCPT       TDLOT     TPITCH      TROLL      XBAR       YBAR
   .0500    -2.8006     -.0045     -.0021      .0022     -.4637      .4918
   .1000    -2.3812     -.0152      .0075      .0082      .4927      .5408
   .1500    -2.6972     -.0386      .0274      .0204      .7102      .5271
   .2000    -2.9234     -.0744      .0602      .0384      .8082      .5161
   .2500    -2.9196     -.1162      .1067      .0588      .9186      .5040
   .3000    -2.6279     -.1526      .1674      .0743     1.1121      .4934
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COMPUTER PROGRAM LISTING

```
      PROGRAM MOMENTA(INPUT,OUTPUT,TAPE6)
      DIMENSION VOD(1001),VE(10),CP(1001),XD(1001)
      DIMENSION IV(20),CPIX(1001),DELXY(20),ITTL(8)
      DIMENSION XOD1(20),XOD2(20),YOD1(20),YOD2(20)
      DIMENSION SDLOT(200),SPITCH(200),SROLL(200),SCPT(200)
      DIMENSION XBARJD(1001),XBARD(20),YBARD(20)
      REAL K1,K2
      JJ=1
      TCPT=0.
      TDLOT=0.
      TPITCH=0.
      TROLL=0.
      PRINT 555
  555 FORMAT(1H ,*INPUT TITLE*)
      READ 103,(ITTL(I),I=1,8)
      WRITE(6,103)(ITTL(I),I=1,8)
  103 FORMAT(8A10)
      WRITE(6,104)
  104 FORMAT(1H ,*     *)
      PRINT 500
  500 FORMAT(1H ,*INPUT NUMBER OF COMPONENTS*)
      READ *,NCOMP
      PRINT 505
  505 FORMAT(1H ,*INPUT NUMBER OF VELOCITY RATIOS AND VALUES*)
      READ *,NVE,(VE(I),I=1,NVE)
      PRINT 509
  509 FORMAT(1H ,*INTEGRATION INTERVALS EQUAL? YES=1,NO=0*)
      READ *,ITEST
      IF(ITEST.NE.1) GO TO 511
      PRINT 508
  508 FORMAT(1H ,*INPUT INTEGRATION INTERVAL*)
      READ *,DXY
      DO 111 I=1,NCOMP
      DELXY(I)=DXY
  111 CONTINUE
      GO TO 512
  511 PRINT 510
  510 FORMAT(1H ,*INPUT INTEGRATION INTERVAL (DELXY) FOR EACH COMPONENT
     1*)
      READ *,(DELXY(I),I=1,NCOMP)
  512 WRITE(6,850)
  850 FORMAT(1H ,3X,*COMP*,6X,*X1*,8X,*X2*,8X,*Y1*,8X,*Y2*)
C**** MATRIX OF COMPONENT DATA ****
      PRINT 520
  520 FORMAT(1H ,*INPUT X1,X2,Y1,Y2 FOR EACH PANEL*)
      DO 80 I=1,NCOMP
      READ *,XOD1(I),XOD2(I),YOD1(I),YOD2(I)
   80 CONTINUE
  205 PRINT 777
  777 FORMAT(1H ,* COMP*,4X,*X1*,8X,*X2*,8X,*Y1*,8X,*Y2*)
      DO 5 I=1,NCOMP
      PRINT 855,I,XOD1(I),XOD2(I),YOD1(I),YOD2(I)
  855 FORMAT(1H ,2X,I2,X,4F10.4)
    5 CONTINUE
      PRINT 508
```

```
  800 FORMAT(1H ,*IS INPUT CORRECT?  YES=1,NO=0*)
      READ *,IINP
      IF(IINP.EQ.1) GO TO 999
      PRINT 200
  200 FORMAT(1H ,*INPUT NO. OF INCORRECT LINES AND VALUES*)
      READ *,NIV,(IV(I),I=1,NIV)
      DO 2 I=1,NIV
      PRINT 770,IV(I)
  770 FORMAT(1H ,*INPUT LINE *,I2)
      READ *,XOD1(IV(I)),XOD2(IV(I)),YOD1(IV(I)),YOD2(IV(I))
    2 CONTINUE
      GO TO 206
  999 DO 81 I=1,NCOMP
      WRITE(6,851)I,XOD1(I),XOD2(I),YOD1(I),YOD2(I)
  851 FORMAT(1H ,4X,I2,4F10.4)
   81 CONTINUE
      WRITE(6,307)
  307 FORMAT(1H ,*     *)
      DO 95 IC=1,NCOMP
      WRITE(6,830)
  830 FORMAT(1H ,*  *)
      WRITE(6,840)IC
  840 FORMAT(1H ,*COMP *,I2)
      WRITE(6,880)
  880 FORMAT(1H ,*-------*/)

C*****CALCULATE YOD(I) AND NY LE 1001 *********

      NY=((YOD2(IC)-YOD1(IC))/DELXY(IC))+1.5

C*****INDIVIDUAL COMPONENT DATA *****

      WRITE(6,700)XOD1(IC),XOD2(IC)
  700 FORMAT(1H ,*X1=*,F6.2,4X,*X2=*,F6.2)
      WRITE(6,710)YOD1(IC),YOD2(IC)
  710 FORMAT(1H ,*Y1=*,F6.2,4X,*Y2=*,F6.2)
      WRITE(6,720)DELXY(IC),NY
  720 FORMAT(1H ,*DELXY=*,F4.2,5X,*NY=*,I3/)
      K=1
      DO 60 I=1,NY
      YOD(I)=YOD1(IC)+DELXY(IC)*(K-1)
      K=K+1
   60 CONTINUE
      DO 20 J=1,NUE
      IF(UE(J).EQ.0.)UE(J)=.00001
      IF(UE(J).GE.0.1) GO TO 73
      WRITE(6,125)
  125 FORMAT(1H ,*RESULTS MAY BE INVALID FOR UE LESS THAN 0.1*)
   73 CPT=0.
      XBAR=0.
      YBAR=0.
      DO 70 I=1,NY
      CPIX(I)=0.
   70 CONTINUE
      DO 30 I=1,NY
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```
C**** CALCULATE CP VS. XOD ****

      XBARJ=0.
      K=0
  100 K=K+1
      XOD=XOD1(IC)+DELXY(IC)*(K-1)
      F=(2.48*YOD(I)-1.6)*VE(J)-.1*YOD(I)-.07
      IF((XOD-F).LT.0.) GO TO 120
      K1=1./(1.1*YOD(I))
      K2=-.13*(YOD(I)-3.5)**2+1.8
      GO TO 130
  120 K1=-1./((-2.28*VE(J)+1.36)*YOD(I))
      K2=(16.*VE(J)/YOD(I))+1.56*ALOG(YOD(I))-1.
  130 A=EXP((4.*VE(J)-1.)**2)
      B=(YOD(I)+.5)**(3.25*VE(J)+1.4)
      CPMAX=-4.25/(A*B)
      C=((K1*(XOD-F))**K2)
      IF(C.GT.10.)C=10.
      D=((XOD+.4*YOD(I)+2.5)**2)
      IF(D.GT.10.)D=10.
      XD(K)=XOD
      CP(K)=(1./EXP(C)-((3.67*YOD(I)+5.)*VE(J)**4)/EXP(D))*CPMAX

C**** CALCULATE AREA UNDER CP VS. XOD CURVE ****

      TEST=(XOD)**2+(YOD(I))**2
      IF(TEST.LE..25)GO TO 40
      IF(K.EQ.1) GO TO 40
      CPI=(CP(K)+CP(K-1))*.5*DELXY(IC)
      XIJ=XOD-.5*DELXY(IC)
      XBARJ=XBARJ+CPI*XIJ
      CPIX(I)=CPIX(I)+CPI
      XBARJD(I)=XBARJ/CPIX(I)
   40 IF(XOD.GT.(XOD2(IC)-.5*DELXY(IC)))XOD=XOD2(IC)
      IF(XOD.EQ.XOD2(IC)) GO TO 90
      GO TO 100

C**** IF INDIVIDUAL COMPONENT DATA IS DESIRED
C**** REPLACE GO TO 90 WITH GO TO 50 AND
C**** ELIMINATE C ON COMMENT CARDS

C  50 IF(I.NE.1) GO TO 750
C     WRITE(6,900)
C 900 FORMAT(1H ,3X,*K*,4X,*I*,7X,*YOD*,8X,*CP*)
C 750 WRITE(6,901)K,I,YOD(I),CPIX(I),XBARJD(I)
C 901 FORMAT(1H ,2I5,3F10.4)
   90 IF(I.NE.NY) GO TO 30

C**** CALCULATE AREA UNDER CP VS. YOD CURVE ****

      MM=NY-1
      DO 10 M=1,MM
      CPIY=(CPIX(M+1)+CPIX(M))*.5*DELXY(IC)
      XI=(XBARJD(M)+XBARJD(M+1))*.5
      YI=YOD(M)+.5*DELXY(IC)
      XBAR=XBAR+CPIY*XI
      YBAR=YBAR+CPIY*YI
      CPT=CPT+CPIY
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      XBARD(IC)=XBAR/CPT
      YBARD(IC)=YBAR/CPT
   10 CONTINUE
      DLOT=(2.*VE(J)**2)*CPT/3.14159
      WRITE(6,910)VE(J),CPT,DLOT
  910 FORMAT(1H ,4X,*VE=*,F10.4,4X,*CPT=*,F10.4,4X,*DLOT=*,F10.4)
      SCPT(JJ)=CPT
      SDLOT(JJ)=DLOT
      SPITCH(JJ)=-1.*DLOT*XBARD(IC)
      SROLL(JJ)=-1.*DLOT*YBARD(IC)
      JJ=JJ+1
      GO TO 20
   30 CONTINUE
   20 CONTINUE
   95 CONTINUE
C**** CALCULATE TOTALS- SUM OF COMPONENTS ****
      WRITE(6,847)
  847 FORMAT(1H ,//)
      WRITE(6,848)
  848 FORMAT(1H ,*TOTALS- SUM OF COMPONENTS*)
      WRITE(6,885)
  885 FORMAT(1H ,*--------*/)
      WRITE(6,300)
  300 FORMAT(1H ,4X,*VE*,7X,*TCPT*,6X,*TDLOT*,4X,*TPITCH*,5X,*TROLL*,5X,
     1*XBAR*,5X,*YBAR*)
      J=0
      KK=0
      LL=0
      MM=0
  400 LL=LL+1
  410 MM=MM+1
      NN=KK*NVE+.5
      TDLOT=TDLOT+SDLOT(LL+NN)
      TCPT=TCPT+SCPT(LL+NN)
      TPITCH=TPITCH+SPITCH(LL+NN)
      TROLL=TROLL+SROLL(LL+NN)
      KK=KK+1
      IF(MM.NE.NCOMP) GO TO 410
      J=J+1
      TXBAR=-1.*TPITCH/TDLOT
      TYBAR=-1.*TROLL/TDLOT
      WRITE(6,450)VE(J),TCPT,TDLOT,TPITCH,TROLL,TXBAR,TYBAR
  450 FORMAT(7F10.4)
      IF(LL.EQ.NVE) GO TO 420
      TCPT=0.
      TDLOT=0.
      TPITCH=0.
      TROLL=0.
      KK=0
      MM=0
      GO TO 400
  420 CONTINUE
      STOP
      END
```

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-8